A DOUBLING OF ANTHROPOGENIC SOLID CONTAMINANTS IN THE STRATOSPHERE AS EVIDENCED BY NASA'S COSMIC DUST COLLECTION.

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Introduction: Every year the Earth's surface accretes about 40,000 tons of extraterrestrial material less than 1 mm in size [1]. These dust particles originate from active comets, asteroids and the Moon and usually remain for a significant time in the stratosphere of the Earth where they are mixed with terrestrial particles of natural and anthropogenic origin. With the recent increase in space activities (Figure 1 [2]) in terms of rocket launches as well as number of objects put into low Earth orbit, one may wonder whether changes in the quantity of anthropogenic material injected in the terrestrial stratosphere can be detected [3].

The NASA Cosmic Dust catalog database is an ideal dataset to test whether this is the case [4, 5].

Methology: In order to study the cosmic dust particles arriving on Earth, the NASA Johnson Space Center (JSC) has been systematically collecting solid dust particles from the Earth's stratosphere by aircraft since 1981. Specially designed particle collectors using collecting surfaces covered with silicone oil (dimethyl siloxane) are each flown for at least tens of hours at an altitude of 20 km aboard NASA U2, ER-2 and WB57F aircrafts and curated after flight in an ultraclean (Class-100) laboratory.

So far, 25 catalogs have been published, covering campaigns of collection from 1981 to 2020, with a total of 5071 solid particles that have been characterized to some degree. In fact, some collectors have not been examined to date, providing a valuable resource for future studies. A preliminary analysis and classification of the dust particles is done based on SEM images, some visual characteristics and X-ray energy-dispersive spectrometry (EDS) composition. The IDPs are classified into four main groups: C (Cosmic), TCN (Terrestrial Contaminant Natural), TCA (Terrestrial Contaminant Artificial) and AOS (Aluminum Oxide Sphere). The AOS particles are expected to originate from rocket exhaust and thus also belong to the TCA class. Cosmic dust particles are typically classified based on a composition close to an average chondritic composition [6]. Figure 2 presents a typical TCA particle composition with elevated metals indicating a likely anthropic origin (Al, Co, Fe) [7].

A 10-fold increase in stratospheric solid particles was previously noticed in the 1970s - 1980s and linked to an increase in rocket launches [8], but this effort has not been continued. Assuming the sampling and processing of the stratospheric particles collection are unbiased, the cosmic dust catalog database should now be used to assess the possible increase in TCA since the 1980s.

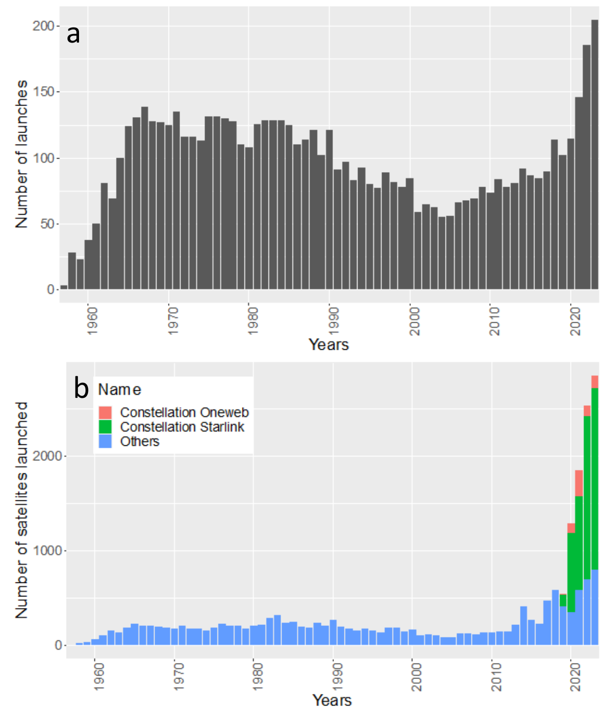

Figure 1: a. Total number of launches per year **b.** Total number of satellites launched per year, highlighting the recent contribution from satellite constellations [2].

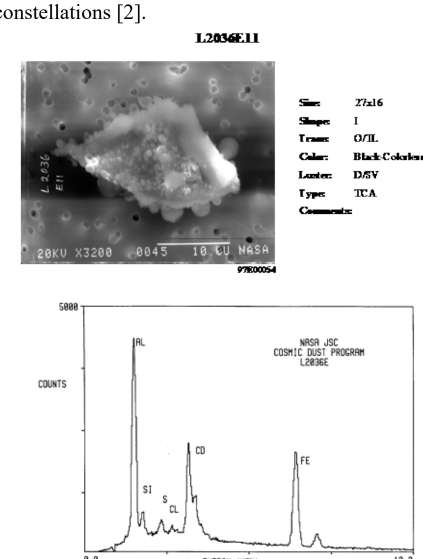

Figure 2: Typical Terrestrial Contaminant Artificial (TCA) particle from catalog 15 [6]

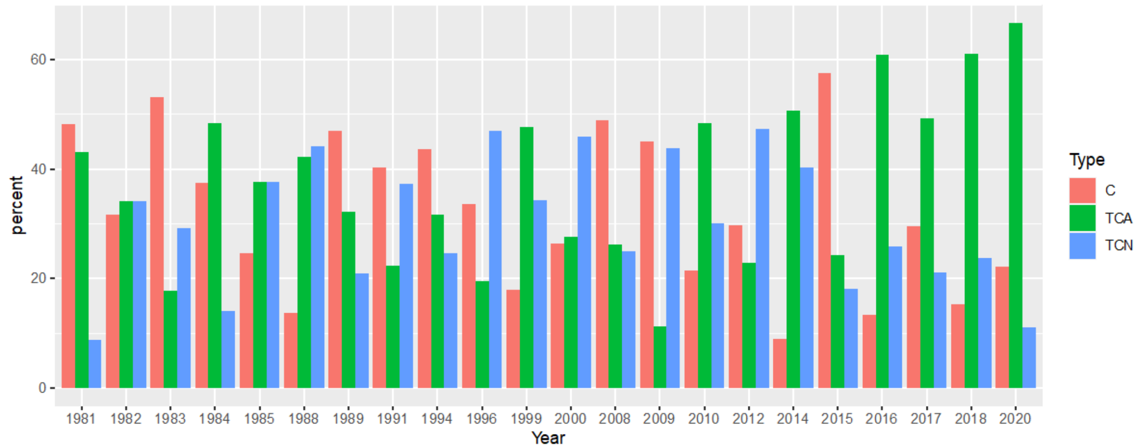

Figure 3: Ratio of the different preliminary types of particles by year of collection of particles published in the NASA Cosmic Dust Catalogs [4, 5]. A significant increase in the proportion of TCA particles can be noticed for the recent years.

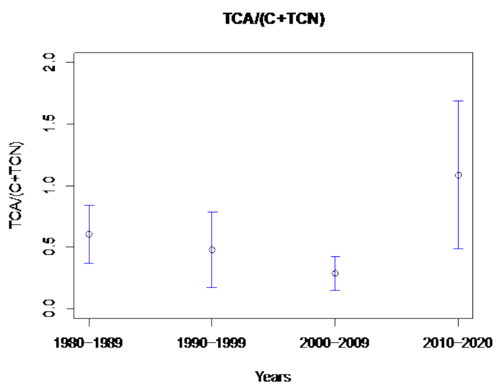

Figure 4: Ratio of the TCA to the C and TCN preliminary types in the NASA Cosmic Dust Catalogs by decades [4, 5].

Results: We have compiled the preliminary EDS data and classes for the >5000 particles contained in the database. The catalogs contain a 'possible type' assignment indicated by question marks. This ambiguous classification has been removed here by confirming the preliminary assignment of these particles Finally, the AOS being anthropogenic contaminants, they were also all included in the TCA class. Based on these simplifications and assuming an unbiased analysis of solid particles presented in the catalogs, Figures 3 and 4 present the percentage fraction of each class with time, per year of collection in Fig. 3 and average per decade in Fig. 4. One can notice that while from 1980 to 2009 the cosmic dust particles typically represent on average 40% of the collection with TCA and TCN corresponding to about 30% each, in the recent years the TCA fraction has doubled to about 60% of the collection (2016-2020). Note that the numbers given for year 2015 are unreliable due to the low total number of particles collected (33), and the unknown duration of the campaign. Since the particles are collected in the lower stratosphere, there is likely enough time for them to sediment and mix well. Assuming that the curation procedure did not introduce any bias with time, our interpretation, following the interpretation from [3], is that this increase in anthropogenic particles could be linked to the continued human space activities and recent increase of rocket launches and satellites reentry.

Conclusions and future work: In this work we have attempted to detect the time evolution in the injection of anthropogenic solid particle contaminants in the Earth's stratosphere by re-analysing the NASA Cosmic dust catalogs preliminary analysis collection covering the last 40 years. We note that the fraction of TCA particles collected in the stratosphere has doubled in the last decade as compared to the previous 30-year period. This increase in anthropogenic particles is likely due to the overall human space activity and its recent increase.

Further work to assess the environmental impact of space activities should include monitoring of the stratospheric aerosols, the determination of the origin of the solid dust particles (whether they come from rocket exhaust, satellite reentry, or other sources), their evolution in the atmosphere (transport) and their possible climatic effects (e.g. on stratospheric ozone).

Acknowledgments: NASA Astromaterials collection program for publishing the Cosmic Dust Catalogs. J. McDowell for publishing online his space launches database.

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